Some Effects of Logging and Associated Road Construction on Northern California Streams[1]

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ABSTRACT

The effects of logging and associated road construction on four California trout and salmon streams were investigated from 1966 through 1969. This study included measurements of streambed sedimentation, water quality, fish food abundance, and stream nursery capacity. Logging was found to be compatible with anadromous fish production when adequate attention was given to stream protection and channel clearance. The carrying capacities for juvenile salmonids of some stream sections were increased when high temperatures, low dissolved oxygen concentrations, and adverse sedimentation did not accompany the logging. Extensive use of bulldozers on steep slopes for road building and in stream channels during debris removal caused excessive streambed sedimentation in narrow streams. Sustained logging prolonged adverse conditions in one stream and delayed stream recovery. Other aspects of logging on anadromous fish production on the Pacific Coast are discussed.

INTRODUCTION

A major concern of resource managers on the Pacific Coast of the United States and British Columbia has been the effect of timber harvest and associated road construction on salmon and trout. At first interest focused on log jams blocking salmon (*Oncorhynchus* spp.) and steelhead trout (*Salmo gairdneri*) from their spawning grounds. California resolved this problem by a law requiring clear passage for fish and by a log jam removal program (Mongold, 1964). Then interest shifted to damage caused by bulldozers working in streambeds and along stream banks (Calhoun, 1962, 1966) and to erosion resulting from improper road and skid trail construction on steep terrains (Cordone and Kelley, 1961; Calhoun, 1967). In July 1966, the California Department of Fish and Game initiated a study in northern California watersheds to determine the effects of logging and associated road building on stream salmonids. This report describes the study from 1966 through 1969 and summarizes the resulting conclusions about streambed sedimentation, water quality, fish food abundance, and stream nursery capacity.

STUDY AREA

Four small streams on the northern California coast were chosen for study (Figure 1): Bummer Lake Creek, South Fork Yager Creek, Little North Fork Noyo River, and South Fork Caspar Creek. They are located within 40 km of the ocean and drain watersheds ranging from 425 to 2,514 ha (Table 1). The watersheds are relatively steep, with canyon sides having mean slopes ranging from 36 to 49%. The coastal climate is characterized by heavy winter rainfall and dry summers. Mean annual precipitation varies from

[1] This study was performed as part of Dingell-Johnson California Project F-10-R, "Salmonid Stream Study," supported by Federal Aid to Fish Restoration funds.

TABLE 1.—*Characteristics of the streams and watersheds*

	Bummer Lake Creek	South Fork Yager Creek	North Fork Noyo River	South Fork Caspar Creek
Drainage area of watershed (ha)	1,400	2,514	989	425
Average canyon slope in study section (%)	45	38	36	49
Stream distance from study section to ocean (km)	28.3	40.0	16.0	11.2
Study section length (m)	1,524	1,119	1,530	3,093
Average stream gradient in study section (%)	5	4	3	3
Average stream width in study section (m)[1]	4.9	5.2	1.5	1.8
Major materials composing streambed surface in study section[2]	cobble & boulder	cobble & boulder	pebble	pebble
Soil series in watershed[3]	Melbourne	Hugo	Hugo	Hugo
Mean annual precipitation (cm)[4]	203	102	127	127
Annual streamflow range liters/sec[5]	14.2–1,416	8.5–934	2.3–396	1.7–255

[1] Measured during minimum flow in summer.
[2] Wentworth's classification (Welch, 1948).
[3] Storie and Weir (1953).
[4] Durenberger (1960).
[5] Range observed during water quality sampling in 1968–69 (Kopperdahl, Burns, and Smith, 1971). Only South Fork Caspar Creek had a streamflow gage and its range exceeded that observed during water quality sampling. South Fork Caspar Creek generally reaches a maximum flow of about 1,189 liters/sec in the winter (Ziemer, Kojan, Thomas and Muller, 1966).

102 to 317 cm. Air temperatures are cooled by dense, recurrent fogs, with the mean maximum temperature in July being about 21 C (Durenberger, 1960). Soils in these drainages are predominately loam and moderately erodible. The combination of steep slopes, heavy rainfall, and erodible soils renders these watersheds unstable. The watersheds are forested with redwood (*Sequoia sempervirens*) and Douglas fir (*Pseudotsuga menziesii*).

Streamflows fluctuate seasonally, with freshets occurring from November to March, and intermittent flows are common in the headwaters during the summer. Minimum streamflows range from 1.7 to 14.2 liters/sec. These small streams are important spawning and nursery areas for coho (silver) salmon (*Oncorhynchus kisutch*), steelhead trout, and cutthroat trout (*Salmo clarki*). Sculpins (*Cottus* spp.) and threespine stickleback (*Gasterosteus aculeatus*) inhabit some of the streams. Coho salmon spawn from November through January. Young salmon emerge from the gravels from February through May and usually spend a year in the stream before emigrating to the ocean. Steelhead trout spawn from December to May. Their young emerge from April to June and remain in the stream from 1 to 4 years before emigrating to the ocean (Shapovalov and Taft, 1954). Cutthroat trout form both resident and anadromous populations in California streams from the Eel River north. Cutthroat trout spawn from October to May, and their young follow a stream life similar to that of rainbow trout (DeWitt, 1954). Fishing pressure on juvenile salmonids is negligible in these streams.

METHODS

Each stream was studied for three summers before, during, and after either logging or road building. This season was selected because it is a critical period for the survival of stream-dwelling salmonids. Living space is limited by streamflow, water temperatures are highest, and most logging occurs in the summer.

Streamflow and stream dimensions were measured systematically within each study stream section (Burns, 1971). Water quality was monitored periodically after logging, while stream temperatures were recorded each summer (Kopperdahl, Burns, and Smith, 1971). Spawning bed sedimentation was measured (Burns, 1970), using techniques similar to those of McNeil and Ahnell (1964). The

FIGURE 1.—Map of the northern California coast showing the location of study streams.

abundance of juvenile salmonids was estimated at selected times in the summers of 1966 to 1969 (Burns, 1971). Fish were captured with a battery-powered, DC, back-pack shocker and populations estimated by the Petersen single-census, mark-and-recovery method (Davis, 1964) or by the two-catch, removal method (Seber and LeCren, 1967). The abundance of fish food and the summer food habits of salmonids in South Fork Caspar Creek were determined (James Burns, John Brode, and Gary Smith, MS; Hess, 1969).

EFFECTS OF LOGGING AND ASSOCIATED ROAD BUILDING ON FOUR CALIFORNIA STREAMS

Bummer Lake Creek

Bummer Lake Creek flows through private lands into the Smith River system, near the California-Oregon border (Figure 1). A portion of its old growth forest was clear cut in alternate blocks on the southwest slope of the stream in the summer of 1968 (Figure 2); 58,000 m^3 of redwood and Douglas fir timber were harvested from 110 ha. Logs were yarded by high lead away from the stream up to the road and by bulldozer above the road. The average horizontal distance between the stream and the road was 120 m, and there were no stream crossings. A bulldozer was operated in the streambed for the removal of logs and other debris from the 1,524-m study section.

Streamflow ranged from 14.8 to 34.5 liters/sec and stream surface area from 0.557 to 0.730 ha during the September surveys (Table 2). Water temperatures remained cool after the logging and never exceeded 18.3 C. In the clear cut blocks bordering the stream, water temperatures were 4.4 C higher than they were in the uncut section upstream. In the cut sections, stream temperatures increased 1.0 C/100 m. In the uncut block between the two cut blocks, stream temperatures cooled 0.5 C/100 m; thus, beyond this shaded area, temperatures were 2.2 C cooler. Water quality remained within limits tolerated by salmonids. No abnormal concentrations of oxygen, carbon dioxide, pH, alkalinity, chloride, sulfate, nitrate, phosphate, or tannin and lignin were detected (Kopperdahl *et al.*, 1971).

The mean percentage of spawning bed sediments smaller than 0.8 mm diameter increased from 10.2 to 13.3% after the logging (Burns, 1970), but the increase was not statistically significant at the 5% level (Student's t-test). The bulldozing of logging debris from the streambed did not fill in pools, erode the stream banks, or cause any adverse conditions. The slight increase in fine materials was probably due to erosion on the cut slopes. Apparently the wide stream channel and boulder-and-cobble bottom prevented the bulldozers from gouging the stream channel.

Fish populations were not adversely affected by the logging. The biomass of salmonids was slightly lower during the logging and increased after it (Table 3). The 19% increase in salmonid biomass to 49.2 kg/ha, however, was within the range of natural variation in unlogged California streams (Burns, 1971). Yearling and older trout were fewer after the logging, but young-of-the-year were more abundant. (Steelhead and cutthroat trout pop-

FIGURE 2.—Aerial view of a portion of the Bummer Lake Creek watershed. Light patches are clear cut blocks, while darker patches are uncut blocks. The white line represents the stream and its forks flowing west. The study section extends from the forks 1.524 in downstream through the second cut block.

TABLE 2.—*Dimensions of the Bummer Lake Creek study section during the September surveys*

Year	Condition	Streamflow (liters/sec)	Length (km)	Pool surface area (ha)	Riffle surface area (ha)	Volume (m^3)
1967	Unlogged	14.8	1.524	0.459	0.270	1,444
1968	Two months after logging	34.5	1.524	0.511	0.219	1,025
1969	Fourteen months after logging and 11 months after stream cleanup	17.0	1.524	0.340	0.217	764

TABLE 3.—*Population densities, mean fork lengths, and absolute numbers of salmonids in Bummer Lake Creek*

	Steelhead rainbow and coast cutthroat trout								
	Young-of-the-year			Yearling and older			Cobo salmon		
Survey date	No./m^2 (kg/ha)	Mean fork length (mm)[1]	Number[1]	No./m^2 (kg/ha)	Mean fork length (mm)[1]	Number[1]	No./m^2 (kg/ha)	Mean fork length (mm)[1]	Number[1]
September 1967	0.62 (14.20)	55 (54–56)	4,509 (4109–4909)	0.14 (25.42)	112 (111–114)	1,003 (797–1209)	0.04 (1.54)	69 (67–71)	279 (221–338)
September 1968	0.39 (13.25)	64 (63–66)	2,916 (2698–3134)	0.10 (18.39)	113 (112–114)	720 (606–834)	0.15 (4.85)	63 (62–64)	1,124 (938–1323)
September 1969	0.93 (28.76)	62 (61–63)	5,175 (5018–5332)	0.08 (19.58)	130 (125–135)	430 (335–525)	0.02 (0.87)	70 (68–72)	111 (98–124)

[1] 95% confidence intervals in parentheses.

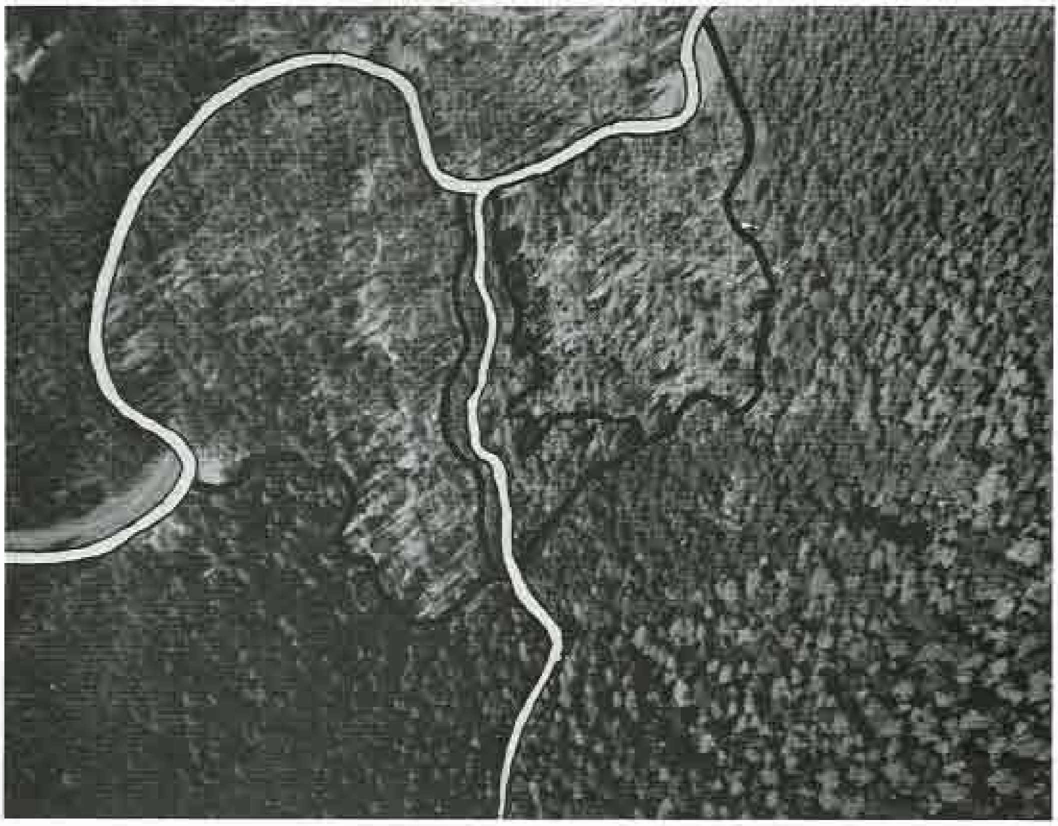

FIGURE 3.—Aerial view of a portion of the South Fork Yager Creek watershed. Center white line represents the stream flowing north to main Yager Creek. Black lines outline area of forest which was selectively logged. A buffer strip was left along the stream.

ulations were pooled because of the difficulty in identifying juveniles in the field; of the older fish that could be identified, about 75% were cutthroat.) All age groups of trout had longer mean lengths after the logging. Coho salmon formed a marginal population in this stream and showed considerable population fluctuation. Their mean length did not change significantly after the logging. Sculpins also increased in biomass after the logging, from 1.3 kg/ha in 1967 to 6.2 in 1968 and 21.8 in 1969.

South Fork Yager Creek

South Fork Yager Creek flows through private lands into the Van Duzen-Eel River System, south of Eureka, California (Figure 1). Old growth timber was cut selectively in the summer of 1968 from the mouth of South Fork Yager Creek upstream 560 m and over an area of 305 m on each side of the stream (Figure 3). Eighty percent of the timber volume was cut from the original volume of 344 m^3/ha. Yarding was done with bull-

TABLE 4.—*Dimensions of the South Fork Yager Creek study section during the August surveys*

Year	Condition	Streamflow (liters/sec)	Length (km)	Pool surface area (ha)	Riffle surface area (ha)	Volume (m^3)
1967	Unlogged	16.9	0.566	0.211	0.099	378
1968	Immediately after logging	14.9	0.566	0.152	0.119	372
1969	Twelve months after logging	20.4	0.566	0.251	0.075	446

TABLE 5.—*Population densities, mean fork lengths, and absolute numbers of steelhead rainbow trout in South Fork Yager Creek*

Survey date	Young-of-the-year			Yearling and older		
	Number/m² (kg/ha)	Mean fork length (mm)[1]	Number[1]	Number/m² (kg/ha)	Mean fork length (mm)[1]	Number[1]
August 1967	1.22 (13.38)	42 (41–43)	3,781 (3522–4040)	0.02 (4.08)	115 (101–129)	65 (25–103)
August 1968	1.08 (21.61)	58 (57–59)	2,932 (2838–3026)	0.04 (8.02)	118 (114–123)	116 (71–161)
August 1969	1.74 (22.60)	48 (47–49)	5,668 (5449–5886)	0.07 (13.46)	123 (120–126)	212 (157–267)

[1] 95% confidence intervals in parentheses.

dozers. Great care was taken to protect the stream during the logging. Riparian vegetation, including merchantable redwood and Douglas fir trees leaning toward the stream, was not cut, and heavy equipment did not enter the stream. Roads and landings were built away from the stream on low gradients.

Streamflow ranged from 14.9 to 20.4 liters/sec and stream surface area from 0.271 to 0.326 ha during the August surveys (Table 4). Water temperatures did not increase after the logging. Temperatures were high in all years, usually reaching 21.5 C in the summer. The protection of riparian vegetation along the stream prevented stream temperatures from increasing to lethal levels after the logging. No abnormalities in water quality were detected after the logging (Kopperdahl *et al.*, 1971).

The mean percentage of spawning bed sedi-

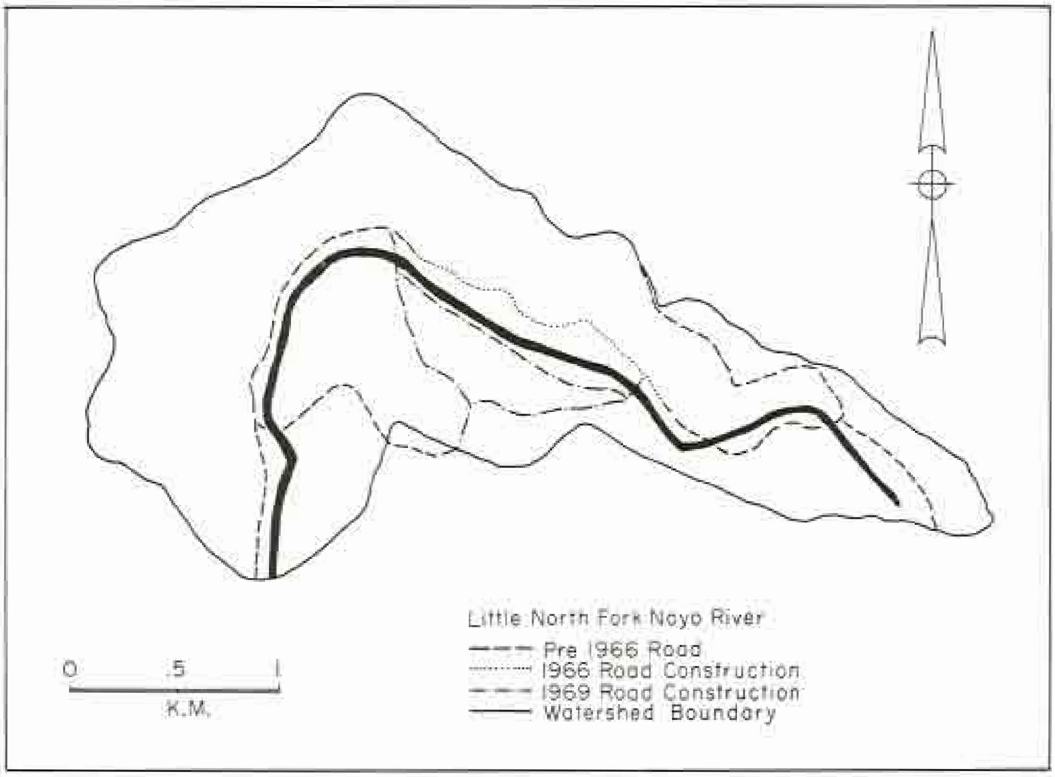

FIGURE 4.—Diagram of Little North Fork Noyo River road construction.

FIGURE 5.—Little North Fork Noyo River received considerable alteration during road construction. The road on the right of the photograph was built in 1966, while the road at the top was built in 1969.

ments smaller than 0.8 mm diameter increased from 16.4 to 22.1% after the logging; however, this increase was not due to the logging but was due to the release of sediments from the collapse of a tree jam-and-rock barrier upstream from the study section (Burns, 1970).

Fish populations increased after the logging (Table 5). The biomass of all age groups of steelhead trout increased and their mean lengths were longer after the logging. The 106% increase in biomass of steelhead trout to 36.1 kg/ha was greater than the natural range of fluctuation in unlogged streams. However, data from an upstream area indicates that this stream was not at carrying capacity during the prelogging population census (Burns, 1971) and, therefore, the entire increase cannot be attributed to the logging. Sculpin and stickleback populations decreased after the logging from 2.3 kg/ha in 1967 to 0.9 in 1968 and 0.4 in 1969.

Little North Fork Noyo River

Little North Fork Noyo River flows through private lands into the Noyo River, near Fort Bragg, California (Figure 1). Its second-growth (logged 100 years ago) redwood and Douglas fir forest has been subjected to selective logging since 1964 (Figure 4). Thirty percent of the timber volume has been removed from 542 ha of watershed since 1966. A bulldozer worked in or near the 1,530-m study section during road construction and right-of-way logging in the fall of 1966 and in the spring of 1969 (Figure 5). Yarding was done with bulldozers. Average distance from the road to the stream was 23 m. There was one bridge crossing at the upper end of the study section.

Streamflow ranged from 2.2 to 7.3 liters/sec and stream surface area from 0.609 to 0.998 ha during the October surveys (Table

TABLE 6.—*Combined dimensions of the four study areas in Little Fork Noyo River during the October surveys*

Year	Condition	Streamflow (liters/sec)	Length (km)	Pool surface area (ha)	Riffle surface area (ha)	Volume (m^3)
1966	Pre-road construction	2.2	0.399	0.414	0.105	93
1968	Twenty-four months after initial road construction and 12 months after gully logging	5.4	0.399	0.619	0.379	122
1969	Immediately after second road construction	7.3	0.424	0.547	0.447	91

6). The selective removal of timber along the stream opened the forest canopy and undoubtedly increased stream temperatures; however, instrument damage and malfunctions prevented collection of stream temperature data before the road construction. Temperatures after the road construction and logging, however, did not exceed 21.1 C. No abnormalities in water quality were detected after the logging (Kopperdahl *et al.*, 1971).

Bulldozer activities increased stream turbidity and spawning bed sediments. After a light rain in November 1969, turbidity reached 53 J. T. U. (Kopperdahl *et al.*, 1971). Two years after the construction of an all-weather road adjacent to the stream, the mean percentage of sediments smaller than 0.8 mm had increased from 20.0 to 31.0% (Burns, 1970). After a second road had been constructed on the other side of the stream and the streamside selectively logged, sediments smaller than 0.8 mm increased to 33.3%. These increases were statistically significant at the 5% significance level (Student's t-test). The pebbles and small gravel composing the narrow stream channel were easily gouged, leaving a heavily silted streambed, with the stream flowing along two bulldozer tracks (Figure 6).

Fish populations decreased as watershed and stream disturbances progressed on Little North Fork Noyo River (Table 7). Steelhead trout numbers remained about the same, but the trout were smaller after the logging, and consequently their biomass decreased 42%. The numbers and biomass of coho salmon decreased more markedly. Biomass decreased 65%, even though the average weight of coho salmon increased as population densities decreased. The total biomass of salmonids decreased 62% to 9.3 kg/ha and this decrease was greater than that of unlogged streams (Burns, 1971). Sculpin abundance decreased each time the streambed became heavily silted, but the sculpins were quick to recover. Before the road construction there were 1.6 kg/ha, and 24 months after road construction there were 11.6 kg/ha. Immediately after the 1969 stream disturbances, the sculpin population was down to 0.4 kg/ha.

South Fork Caspar Creek

Caspar Creek, which flows through Jackson State Forest just south of Fort Bragg, received

FIGURE 6.—After a bulldozer operated in the streambed of Little North Fork Noyo River, the streamflow split into two separate channels, each formed by bulldozer tracks.

TABLE 7.—*Population densities, mean weights, and absolute numbers of salmonids in Little North Fork Noyo River*

Survey date	Steelhead rainbow trout Number/m² (kg/ha)	Steelhead rainbow trout Mean weight (g)[1]	Steelhead rainbow trout Number[1]	Coho salmon Number/m² (kg/ha)	Coho salmon Mean weight (g)[1]	Coho salmon Number[1]
October 1966	0.03 (3.66)	11.8	19 (11–27)	1.15 (20.70)	1.8	698 (672–724)
October 1968	0.03 (1.73)	6.0 (4.8–7.2)	29 (23–35)	0.40 (9.66)	2.4 (2.2–2.6)	403 (390–416)
October 1969	0.03 (2.14)	8.6 (5.6–11.5)	25 (24–26)	0.26 (7.15)	2.8 (2.5–3.0)	255 (238–272)

[1] 95% confidence intervals in parentheses.

more attention than the other study streams since there was an interagency program (U. S. Forest Service, California Division of Forestry, California Department of Water Resources, Humboldt State College, and California Department of Fish and Game) to determine the effects of road construction on streamflow, sedimentation, fish life, and fish habitat (U. S. Forest Service, 1965).

The South Fork's second-growth forest of redwood and Douglas fir was disturbed by 6.0 km of road construction in the summer of 1967 (Figure 7). Nineteen thousand-four hundred m of sawlogs were harvested and 18,800 m³ of road materials moved during the road right-of-way construction. The road was built adjacent to the stream, ranging from four bridge crossings (Figure 8) to 76 m at the furthest point from the stream. Road materials were side-cast into a portion of the stream and 79 m of the stream were relocated.

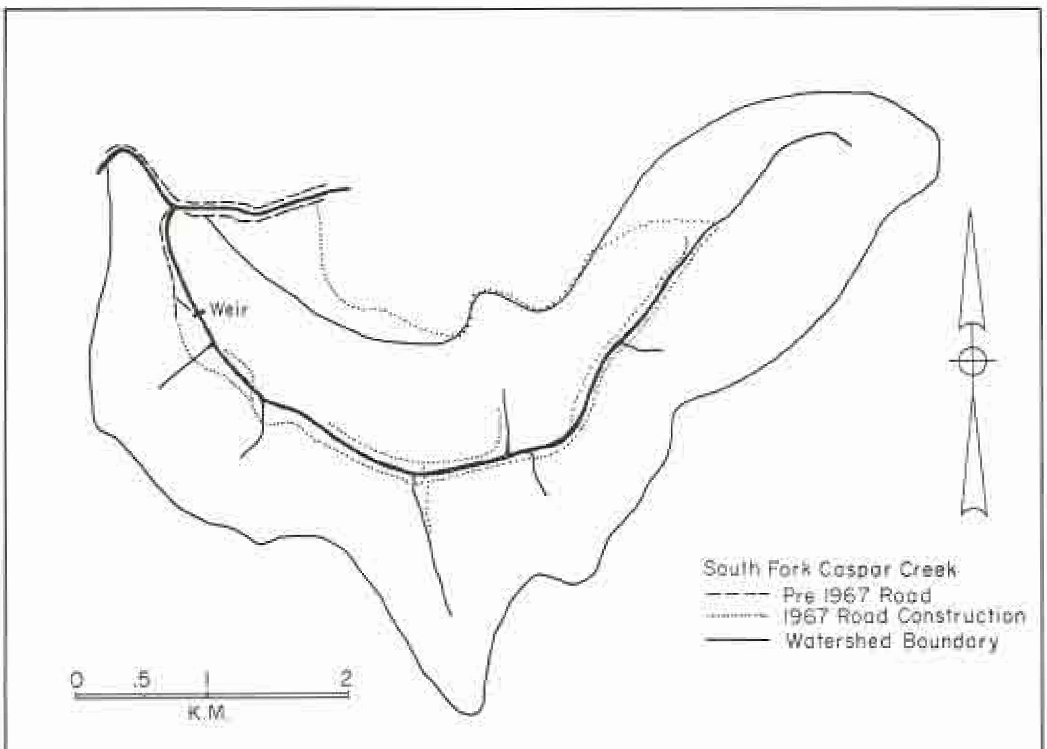

FIGURE 7.—Diagram of South Fork Caspar Creek road construction.

FIGURE 8.—South Fork Caspar Creek, showing one of the four bridge crossings and the stream disturbance resulting from bridge construction.

A bulldozer operated through 41% of the 3,093-m study section during the yarding of logs and the removal of debris. Most of the fill slopes, secondary roads, and streambank were fertilized with urea and seeded with annual rye grass (*Elymus* sp.) at a rate of 56 kg/ha. No logging trucks used the road after the first summer. Road slides occurred during

TABLE 8.—*Dimensions of the South Fork Caspar Creek study section during the June and October surveys*

Year	Condition	Streamflow (liters/sec)	Length[1] (km)	Pool surface area (ha)	Riffle surface area (ha)	Volume (m^3)
June 1967	Pre-road construction	12.7	3.091	0.295	0.307	367
October 1967	Immediately after road construction	4.6	2.806	0.193	0.301	226
June 1968	Eight months after road completion	8.0	3.039	0.290	0.210	305
October 1968	Twelve months after road completion	2.5	2.723	0.216	0.191	186
June 1969	Twenty-two months after road completion	12.8	3.031	0.367	0.289	400
October 1969	Twenty-three months after road completion	5.1	2.887	0.234	0.162	234

[1] Variable length due to intermittent flow drying some stream sections.

the winter and road repair was necessary in the springs of 1968 and 1969.

Streamflow ranged from 12.8 to 2.3 liters/sec and stream surface area from 0.656 to 0.396 ha during the June and October surveys (Table 8). Prior to the road construction, the amount of solar radiation received at some stations along the stream was less than 5% of the total available at that latitude. Even on clear days, about half of the stream received less than 10% of the available radiation because of the dense streamside vegetative canopy. Absolute values ranged from 7 to 276 langleys/day (DeWitt, 1968). After the road construction some stations along the South Fork received 140% more radiation than they had previously. The absolute average increased 98 langleys/day. Increased solar radiation increased stream temperatures. Water temperatures increased as much as 11.1 C during the road construction at some South Fork stations (Hess, 1969). The maximum observed temperature was 25.3 C (DeWitt, 1968). The maximum preconstruction temperature at the downstream end of the study section was 13.9 C (Kabel and German, 1967), while the postconstruction maximum for this station was 21.1 C.

During the logging, dissolved oxygen dropped to 5 ppm in some isolated pools with decaying slash, while undisturbed stream sections had 10 ppm (Richard Brandon, Humboldt State College, pers. comm.). In August 1968, 11 months after cessation of the right-of-way logging, the concentration of carbon dioxide was 8 ppm (Kopperdahl *et al.*, 1971). However, this level of carbon dioxide is not lethal to salmonids (McKee and Wolf, 1963). The increase in carbon dioxide probably resulted from decomposition of logging slash in the streambed. Unlogged streams on the coast had concentrations of carbon dioxide of less than 2 ppm during this same period (Kopperdahl *et al.*, 1971). Other concentrations of chemicals within South Fork Caspar Creek were generally normal.

High turbidities were localized in areas where a bulldozer was working in the stream during bridge construction. Silt extended only a short distance downstream from the disturbance and the stream cleared quickly upon cessation of bulldozer activities. During a moderately heavy rainfall in the first winter after road construction, erosion and slippage of the road caused turbidities of 3,000 ppm and deposition of as much as 0.6 m of sediment in the stream (Hess, 1969). The volume of sediments smaller than 0.8 m increased from 20.6 to 34.2% immediately after road construction. The next summer this class of sediments returned to the predisturbance level. Twenty-two months later, however, this class of sediments was up to 28.5%. These changes in streambed composition were statistically significant at the 5% significance level. The initial increase in 1967 followed extensive use of a bulldozer to clear the stream of logging debris (Figure 9). The narrow streambed composed of small materials was particularly susceptible to degradation. Erosion was lessened the first winter and spring by planting annual rye grass on the stream banks, fill slopes, and skid trails. Without excessive erosion, accumulated sediments were scoured from the riffles by the summer 1968. The increase in 1969 resulted from erosion of the streambank, side casts, and slides.

The road construction and right-of-way logging were immediately detrimental to most aquatic invertebrates in South Fork Caspar Creek, although conditions favored Diptera and Plecoptera (J. W. Burns, J. M. Brode, and G. E. Smith, MS). Increases in these two orders offset the losses in other invertebrates, causing an increase in benthos from 286 mg/m^2 to 634 mg/m^2 (120% increase) immediately after the road construction and fertilization with 817 kg urea. North Fork Caspar Creek (an unlogged, second-growth stream used as one of the controls for this study) also showed a 120% increase in benthos; therefore, the immediate increase in the South Fork cannot be interpreted as being caused by the road construction and fertilization (J. W. Burns, J. M. Brode, and G. E. Smith, MS). Recolonization of the South Fork was rapid and, within two years, the South Fork's benthos increased 370% over the preroad construction biomass. The North Fork's benthos increased only 64% during the same period (J. W. Burns, J. M. Brode, and G. E. Smith, MS). Ephemeroptera took longer to recover

FIGURE 9.—South Fork Caspar Creek was grossly altered by road construction. The primary cause of damage was the operation of bulldozers in the stream channel.

than did most other insect orders. Trichoptera recovered rapidly and along with Plecoptera and Diptera made up the majority of the South Fork's benthos. Trichoptera drift increased more than drift of other orders after the road construction. The occurrence of terrestrial organisms in the drift appeared to be influenced only slightly by the disturbance. The total drift increased 47% by the first spring after the road construction and 100%

TABLE 9.—*Population densities, mean fork lengths, and absolute numbers of salmonids in South Fork Caspar Creek*

Survey date	Steelhead rainbow trout						Coho salmon		
	Young-of-the-year			Yearling and older					
	No./m² (kg/ha)	Mean fork length (mm)[1]	Number[1]	No./m² (kg/ha)	Mean fork length (mm)[1]	Number[1]	No./m² (kg/ha)	Mean fork length (mm)[1]	Number[1]
June 1967	1.69 (11.81)	37 (36–38)	10,183 (9507–10859)	0.11 (10.26)	86 (78–93)	673 (362–984)	1.00 (15.90)	47 (45–48)	6,001 (5613–6389)
October 1967	0.29 (4.94)	50 (48–52)	1,436 (1313–1559)	0.02 (4.53)	124 (112–135)	106 (95–117)	0.21 (5.45)	58 (56–60)	1,038 (962–1114)
June 1968	1.32 (10.51)	43 (42–44)	6,580 (6473–6687)	0.04 (3.65)	95 (92–99)	176 (141–211)	0.50 (7.42)	49 (48–50)	2,510 (2452–2568)
October 1968	0.58 (12.77)	58 (57–59)	2,363 (2307–2419)	0.01 (2.13)	115 (108–122)	51 (33–69)	0.32 (5.78)	54 (53–55)	1,283 (1244–1322)
June 1969	1.45 (17.38)	47 (46–48)	9,512 (9238–9786)	0.06 (5.70)	92 (89–94)	407 (303–511)	0.77 (11.62)	51 (50–52)	5,036 (4833–5239)
October 1969	0.81 (17.07)	57 (56–58)	3,224 (3153–3295)	0.04 (5.23)	111 (107–113)	141 (91–191)	0.48 (8.08)	54 (53–55)	1,885 (1849–1921)

[1] 95% confidence intervals in parentheses.

by the second spring. The weight of insects dropping into the South Fork doubled over the preroad construction values (Hess, 1969). The greatest increase was in those having aquatic immature stages, the increase being exceptional in Trichoptera and Diptera. Aquatic organisms were more important in the diets of steelhead trout and coho salmon than were terrestrial organisms. Diptera became more important in the diets of South Fork salmonids after the road construction.

Salmonid populations decreased immediately after the road construction (Table 9). Recovery began the following spring and by the second spring the salmonid biomass was only?20% lower than the predisturbance biomass of 38.0 kg/ha. All age groups of salmonids had greater mean lengths after the road construction. The road construction may have reduced the total yield of coho salmon and steelhead trout smolts in 1968 and 1969, because of high mortality of both species and the premature emigration of yearling and older steelhead trout in 1968 (Graves and Burns, 1970). Population changes in the summer (June to October) were highest in 1967, when the road was built into the South Fork's watershed. The population of young-of-the-year (Age +) steelhead trout decreased 85%, older (Age 1+) steelhead trout decreased 84%, and coho salmon decreased 82%. These rates were much higher than the average decreases of 65% for Age + steelhead trout, 68% for Age 1+ steelhead trout, and 55% for coho salmon in 1968 and 1969. The oversummer loss of South Fork salmonids was also higher than the decrease observed for the same period in North Fork Caspar Creek. In the summer of 1967, these were 69, 25, and 16% for the respective species and age groups in the North Fork (Burns, 1971). Some of the decrease in the South Fork in 1967 may have resulted from emigration of some large steelhead trout from the study area to the pools formed behind the streamflow gaging and fish trapping facilities. Downstream migrant census data for the spring of 1968 suggest that these pools provided refuge for a few fish during road construction (Graves and Burns, 1970). In the strict sense, then, not all of the decrease was mortality. In 1968 downstream migrants in both the North and South Forks were monitored from June to October. Only young-of-the-year fish entered the traps, with 6 steelhead trout and three coho salmon trapped in both forks. These data suggest that few fish normally migrate downstream in Caspar Creek during the summer. The combined smolt yield of steelhead trout and coho salmon in the South Fork for the spring of 1968 was 20% lower than the preroad construction smolt yield, but was within the range of other California streams (Graves and Burns, 1970). Stickleback biomass fluctuated widely during the study, showing an overall increase after the road construction. June and October biomasses were: 0.2 to 0.7 kg/ha in 1967, 6.6 to 2.5 in 1968, and 1.1 to 5.0 in 1969.

DISCUSSION

Studies of the effects of logging reported from California, Alaska (Sheridan and McNeil, 1968; Meehan, Farr, Bishop, and Patric, 1969), and Oregon (Hall and Lantz, 1969) suggest that logging is compatible with anadromous fish production if adequate attention is given to stream and watershed protection and channel clearance. Under special circumstances, stream salmonid production can even be enhanced by logging. Cold streams, shaded by dense forest canopies are not optimum trout habitats (White and Brynildson, 1967). Thinning the riparian canopy allows a greater total solar radiation to reach the stream, raising temperatures a few degrees (viz., Bummer Lake Creek), and increasing the production of bacteria, algae, and the insects upon which fish feed (viz., South Fork Caspar Creek). Salmonid biomass increased in two California streams (Bummer Lake Creek and South Fork Yager Creek) after the streams were carefully logged.

Temperature increases can be predicted and modified by leaving shade along the stream (Brown, 1969). A dense understory or buffer strip (e.g., South Fork Yager Creek) can effectively keep temperatures cool. Alternating cut and uncut sections (e.g., Bummer Lake Creek) can be used to control temperatures. Increases are at least partially reversible if the warmed water passes through shaded areas.

Logging often results in higher summer streamflow (Rothacher, 1965; Hibbert, 1967), providing more living area for juvenile salmonids and thereby increasing the fish rearing capacity of the stream. If protective logging is compatible with fish production, then what logging activities are incompatible or need special attention? Chapman (1962) reviewed many of the effects of logging on fishery resources; many of his points are reviewed here and others observed in this study and in Oregon (Hall and Lantz, 1969) are discussed.

Removing too much of the forest canopy, such as cutting all or a major portion of a watershed, can have drastic results for salmonids. Warmed waters entering the main stream from several logged tributaries may increase main stream temperatures beyond those tolerated by salmonids. Temperatures above 25 C for extended periods are usually lethal to salmonids (Brett, 1952). Streams can reach lethal temperatures or, more commonly, levels which increase metabolic rates and maintenance requirements, increase pathogenic activity, and decrease the solubility of oxygen. These dangers are even more critical inland, away from cooling influences of coastal fog. Temperatures of California streams within the coastal fog belt did not exceed 21 C for extended periods. Trout production in some sections of Berry Creek, Oregon, was not increased by removing the forest canopy, even though the amount of solar radiation reaching the cleared sections was triple that reaching the shaded sections. Algal production was much higher in the cleared sections; however, this increase was offset by decreases in terrestrial plant debris available for insect foods (Warren, Wales, Davis, and Doudoroff, 1964). Terrestrial detritus and leaf fragments are apparently more important as food to insects eaten by coho salmon than are aquatic plants (Chapman and Demory, 1963).

Extensive use of bulldozers on steep slopes or in stream channels can cause excessive erosion which can be deleterious to salmonid reproduction. Small streams with narrow channels seem most vulnerable to this type of damage. The mean volumes of streambed sediments smaller than 0.8 mm in Little North Fork Noyo River and South Fork Caspar Creek exceeded 30% during the logging but probably were less during the salmon and steelhead spawning periods (Burns, 1970). Had fine sediments remained this abundant after the spawning, salmonid survival to emergence would probably have averaged less than 10% (Hall and Lantz, 1969). Building roads away from the stream (viz., Bummer Lake Creek), or leaving a buffer strip (viz., South Fork Yager Creek) to intercept sediments and slash protects the stream habitat. Seeding the disturbed areas with grass (viz., South Fork Caspar Creek) mitigates the damage. Streambed compaction which prevents the digging of redds or impairs the emergence of fry was not observed in the California streams studied, but has been observed in other California streams.

Excessive erosion from logging frequently fills pools necessary for the rearing of larger salmonids (Fisk, Gerstung, Hansen, and Thomas, 1966). Pools filled with sediment in Little North Fork Novo River and South Fork Caspar Creek were scoured during each winter after the road construction and logging, thus providing adequate living space the following year. However, both streams built up numerous sediment bars, thus forming unstable streambeds with considerable gravel movement during periods of high streamflow. Extensive streambed movement is not unusual for California streams. For example, in unlogged North Fork Caspar Creek as much as 2.3 m^3 of sediment per hectare of watershed has been deposited behind the streamflow gaging weir in a single year (Jay S. Krammes, U. S. Forest Service, pers. comm.). After road construction, the greatest amount of sediment deposited behind the South Fork Caspar Creek weir in one year was 0.7 m^3/ha.

Logging often results in higher peak streamflows and more rapid attainment of peaks (Hibbert, 1967). High flows accompanying a large deposition of sediments from side slope and streambank erosion will cause a great deal of streambed movement and stream turbidity. Streambed movement can crush and dislodge developing salmonid embryos and fry (James, 1956). Excessive turbidity is especially condemned by fishermen, since it limits their fishing days.

Another important consideration is the time of year when the logging occurs. Felling trees into the stream when embryos and fry are in the gravel is deleterious, since decaying slash depletes intragravel dissolved oxygen (Hall and Lantz, 1969) or produces copious amounts of slime bacteria (*Sphaerotilus*) which suffocate developing eggs and alevins (Gordon and Martens, 1969). This emphasizes the importance of keeping excessive amounts of slash out of streams. Because most of this slash was removed after the logging, dissolved oxygen concentrations in the California streams studied were generally at saturation. The most desirable practice is to keep all timber out of the stream. In my investigations, the major reason bulldozers entered stream channels was to remove logging debris. Another reason for keeping timber out of streams is to prevent the continual formation of log jams. Few loggers remove all trees, limbs, and other debris to above the high water level. Usually streams have to be cleared after each winter, since high water washes materials back into the stream, where they accumulate and form new barriers to fish migration.

Sustained logging and associated road construction over a period of many years do not afford either the stream or the fish population a chance to recover. Logging operations on the California streams studied were usually limited to one season and to only a small fraction of the total watershed. Had the watersheds been more extensively logged, changes may have been more severe. Prolonged disturbances (viz., Little North Fork Novo River) damage stream habitat and fish populations. Logging operations should be completed in the shortest time possible and then the watershed left to recover. South Fork Caspar Creek recovered quite rapidly from extensive stream damage, although recovery may have been accelerated by streamside fertilization and seeding and by scheduling the major logging operation after the stream had recovered from the road construction. My studies and those in Oregon demonstrate that coho salmon and steelhead trout are resilient fish, able to compensate for adversities. Generally, the yields of downstream migrants were not drastically reduced and juvenile populations recovered rapidly. In a clear cut operation in a Douglas fir watershed in Oregon, the numbers of juvenile coho emigrating to the ocean during the two years after the logging were within the range of variation recorded before the logging (Hall and Lantz, 1969). Some fish killed in the summer during the logging would die during this period, anyway. In the summer, when populations are large and mortality is great, the impact of logging is not as severe as it is in the period following population adjustment to stream carrying capacity. In the fall and spring, when smolts are preparing for their downstream migration, the added mortality caused by logging could have serious consequences. The loss of yearling and older fish killed during this period would have a direct effect upon smolt yields. In some of the California streams studied (Bummer Lake Creek and South Fork Caspar Creek), there were fewer yearling and older trout after the logging. The impact of this decrease on smolt yields is not well understood since the loss of older trout may be mitigated by the increased growth and survival of the remaining fish. However, it is known that the larger, older smolts have the highest ocean survival (Shapovalov and Taft, 1954). The prime objective of protecting anadromous fish streams from adverse watershed use is to maintain the quality and quantity of smolts entering the ocean. A secondary objective is to maintain water clarity, so that anglers can effectively fish for adults.

ACKNOWLEDGMENTS

California biologists Paul M. Hubbell, Fredric R. Kopperdahl, and David S. Graves (deceased) assisted in field collections and data analyses. Many other agencies and lumber companies provided assistance during the study and made valuable suggestions regarding the manuscript. These include: U. S. Forest Service, California Division of Forestry, California Department of Parks and Recreation, California Department of Water Resources, Humboldt State College, Rellim Redwood Co., Pacific Lumber Co., and Boise Cascade Timber Products. Mr. David M. Burns of the California Division of Forestry provided revised estimates on the volume of road materials moved, the length of stream rechanneled, and the amount of timber harvested from South Fork Caspar Creek. This accounts for the discrepancy in these values between this report and my previous reports on sedimentation (Burns, 1970) and downstream migrants (Graves and Burns, 1970).

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